Effects of different N sources on growth, nutrient uptake and ionic balance of *Larlix gmelini* seedlings

CHEN Yong-liang
(*Northeast Forestry University, Harbin 150040, P. R. China*)

HAN Shi-jie
(*Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P. R. China*)

SU Bao-ling
(*Shenyang University, Shenyang 110016, P. R. China*)

Abstract: The effect of different sources and levels of N on dry matter production, nutrient uptake and ionic balance of *Larlix gmelini* was studied. The results showed that the growth of the plants fertilized with ammonium was not as good as the control treatment. The growth of the plants fertilized with ammonium nitrate did not differ significantly from that in control or nitrate treatment, but was better than that in the ammonium treatment. Total cation concentrations in shoots varied little with N level in the ammonium and ammonium nitrate treatments, while those in the shoot increased with N level in the nitrate treatment. The treatments had little effect on the anion concentrations in the shoot. In the roots, the concentrations of both cations and anions changed little except for SO_4^{2-} and Ca^{2+}. There existed a higher carboxylate production in the plants fertilized with nitrate. The ratio between the production of carboxylate and the production of organic N $\Delta(C\text{-}A)/\Delta N_{org}$ was constant with N supply in the plants receiving nitrate, but obviously declined with N supply for ammonium-fed plants. $\Delta(C\text{-}A)/\Delta N_{org}$ values were intermediate between those of the nitrate and the ammonium-fed plants as for the mixed N source.

Key words: N resource; Growth; Nutrient uptake; Ionic balance
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Introduction

The form in which nitrogen is absorbed by plant largely determines the acidifying or alkalizing effects of plants nutrient uptake. From the studies of ionic balance it can be concluded that ammonium nutrition can always lead to H^+ excretion, while nitrate nutrition can always give rise to OH^- excretion (Smiley, 1974; Troelstra *et al.*, 1985; Marschner, 1983; Rollwagen *et al.*, 1988; Gijsman, 1990). From the nutrients absorption, nitrogen and sulphate will be partly assimilated to organic form. The remaining content of inorganic cations and anions, including free NH_4^+, NO_3^- and SO_4^{2-}, usually will not be in stoichiometric balance. The difference C-A refers to the surplus in positive charge of inorganic ions in the plant, which is usually compensated by organic anions or carboxylates (Keltjens, 1981). The size of the carboxylate pool C-A is influenced by process of uptake (uptake cations >uptake anions or vice versa), the reduction of nitrate and sulphate, and the utilization of ammonium. The $\Delta(C\text{-}A)/\Delta N_{org}$ ratio of the whole plant may provide identities about the extent of ammonium nutrition relative to nitrate nutrition and about the influence of the plant on the rhizosphere soil pH (Troelstra, 1983). Bledsoe and Rygiewicz (1986) determined nutrient uptake and H^+/OH^- excretion of Douglas fir and several other coniferous species. They found that the amount of H^+/OH^- ions excreted per unit nitrogen taken up was much higher than commonly reported for other plant species. They also found a very high production of carboxylates and concluded that the ionic balance in conifers might be regulated in a different way compared with the other species. This study was to investigate the dry matter production and ionic balance of *Larlix gmelini* seedlings with different sources and levels of nitrogen.

Materials and methods

The soil was sampled from Changbai Mountain Research Station of Ecosystem, Chinese Academy of Sciences. It was collected from the upper 20 cm soil layer after the litter was removed. The soil was sieved to remove stones and dead fine roots. The general physical and chemical properties of the soil were analyzed by the standard method issued by the State Standard Bureau.

The experiment was carried out with two years old *Larlix gmelini* seedlings. The seedlings were planted in 3-liter

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Biography: CHEN Yong-liang (1969-), male, Ph. Doctor, lecture of Northeast Forestry University, Harbin 150040, Post-doctor in Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, P. R. China.
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pots with 3.5 kg dark brown forest soil, one seedling in each pot. There were ten pots per treatment. The soil was covered with a layer of quartz sand to reduce evaporation. Three different forms of nitrogen were applied: NO_3^- as $Ca(NO_3)_2$, NH_4^+ as NH_4Cl and NH_4NO_3. Three N levels, 20, 60 and 120 mg kg^{-1} respectively, were added for each nitrogen form. A control experiment without nitrogen was included at the same time. All nutrients were added as solutions and completely mixed with the soil. Nitrification inhibitor was mixed with soil in all treatments at a rate of 10 mg kg^{-1} in order to prevent conversion of NH_4^+ to NO_3^-. The pots were maintained at fixed moisture of 0.18 $cm^3\ cm^{-3}$ by adding distilled water during the plant growth. After 12 weeks the seedlings were harvested. Shoot and roots were separated and the shoots were divided into needles and wood parts, the latter fraction also included the young branches that had not lignified yet. Both fractions were dried at 68℃. The roots were lightly rinsed with water, removing the adhering soil and sand. The cleaned roots were also dried at 68℃ and weighed. Root dry matter weight was corrected, assuming a 20% loss because a considerable loss of dry matter may occur during cleaning. So the final root dry weights were obtained by multiplying the measured weights by 1.25. Finally, shoots, including needles and woody parts, and roots were analyzed for N, P, K, Ca, Mg, Na, NO_3^--N, NH_4^+-N, organic N and SO_4^{2-}-S, which are the elements needed to calculate the ionic balance. All analysis was also carried out by standard method issued by the State Standard Bureau.

For determination of initial dry matter weight and chemical composition, 10 seedlings were selected randomly from the planting material at the start of the experiment. All the processing methods described above were also performed on these seedlings.

Results and discussion

Growth and dry matter production

Differences between the treatments were observed after 10 weeks. All the plants fertilized with only ammonium had a poor appearance and grew obviously slower than plants fed with one of the other two nitrogen sources. The color of the needles was dull green or even yellowish and young shoots did not elongate. Four out of 10 plants fertilized with the highest NH_4^+-N level died by that time. There was little difference in plant appearance between the nitrate and ammonium nitrate treatments. Dry matter production of the plants is given in Table 1. In the nitrate treatments, 120 mg kg^{-1} N treatment somewhat retarded the growth compared with the control treatment, while at 20 and 60 mg kg^{-1} N the production increased considerably.

The growth of the plants fertilized with ammonium was not as good as the control treatment. With increasing ammonium concentration, growth of both shoot and roots decreased. The growth of plants fertilized with ammonium nitrate did not differ significantly from that in the control or nitrate treatment, but was usually much better than that in the ammonium treatment.

The relative distribution of dry matter production for wood, needles and roots was obviously different for the ammonium treatments compared with other treatments. The ratio of shoot growth to root growth obviously increased with N level in the case of ammonium, while with both nitrate and ammonium nitrate have only slight changes for different N levels. As far as only the shoot was concerned, there existed an increasing fraction of the dry matter in the needles in the case of the ammonium treatment, while with the other two treatments the distribution of dry matter between needles and wood remained almost constant.

The result above showed that ammonium was an inferior source of nitrogen for *Larlix gmelini.* The dry matter production by the plants fertilized with ammonium were even lower than that of the control plants, which means that the additional ammonium supply may lead to disturbance of certain physiological functions, even the regular growth. Except the highest N level plants fertilized with ammonium nitrate did not grow as well as those fed with nitrate alone.

Table 1. Average dry matter weight (g $plant^{-1}$) of *Larlix gmelini* in different sources and levels of nitrogen (mg· kg^{-1})

Treatment	Wood	Needles	Shoot	Roots	Total production
Initial	5.12	5.89	11.01	4.91	0.00
Control	8.50	10.93	19.43	9.70	13.21
NO_3 20	11.64	13.25	24.89	11.35	20.32
NO_3 60	12.87	14.71	27.58	11.76	23.42
NO_3 120	9.13	10.24	19.37	9.25	12.70
NH_4 20	9.74	10.02	19.76	9.27	13.11
NH_4 60	7.08	9.81	16.89	7.03	8.00
NH_4 120	6.55	9.07	15.62	6.21	5.91
NH_4NO_3 20	10.96	12.00	22.96	9.89	16.93
NH_4NO_3 60	11.68	12.57	24.25	10.27	18.60
NH_4NO_3 120	9.97	10.92	20.89	9.86	14.83

Nutrient element composition

The concentrations of cations and anions in shoots and roots are given in Table 2. An increase in N supply raised the N concentrations in the plant regardless of the sources. In the shoot, the increases were a little smaller in the case of ammonium treatment, while the increases were considerable for the nitrate and ammonium nitrate treatments. As far as the roots were concerned, the increases in N concentration were smaller for all forms of nitrogen compared with shoots. Free nitrate concentrations in the plant were low except that at the highest level of nitrate and ammonium nitrate. The shoot nitrate concentrations exceeded very low levels. Free ammonium concentrations all exceeded very low levels for all forms and levels of nitrogen. The concentrations of Mg^{2+}, Ca^{2+} and Na^+ in the shoot increased with the increasing nitrate supply, while K^+ concentrations decreased slightly. Total cations concentrations in the shoot varied little with N level in the ammonium and ammonium nitrate treatments, while those increased with N level in the nitrate treatment. The treat-

level in the nitrate treatment. The treatments had little effect on the anion concentrations in the shoot except in the case of sulphate. The higher sulphate concentrations in the case of ammonium treatment were probably because the ammonium was supplied as ammonium sulphate. The total anion concentrations decreased with ammonium supply, but increased with nitrate supply.

Table 2. Total nitrogen, cation (C), anion (A) and carboxylate (C-A) concentration (mmol kg^{-1}) of *Larlix gmelini* in different sources and levels of N supply (mg· kg^{-1})

	N	NH_4^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	ΣC	NO_3^-	SO_4^{2-}	P	Cl^-	ΣA	C-A
Shoots													
Initial	652	29	169	151	91	7	447	1	82	47	13	143	304
Control	715	31	276	132	118	23	580	8	153	39	17	217	363
$NO_3$20	796	32	251	137	116	18	554	9	136	35	15	195	359
$NO_3$60	1080	47	230	172	128	25	602	10	109	34	17	168	434
$NO_3$120	1175	35	239	238	147	31	690	41	78	38	19	176	514
$NH_4$20	687	36	206	151	125	29	547	9	187	41	21	258	289
$NH_4$60	759	51	197	143	122	26	539	8	190	40	25	263	276
$NH_4$120	902	54	200	148	119	30	551	9	231	32	22	294	257
$NH_4NO_3$20	698	37	241	136	117	28	559	8	178	26	20	226	333
$NH_4NO_3$60	1081	48	225	137	128	24	566	9	161	30	19	219	347
$NH_4NO_3$120	1096	42	222	147	127	27	565	19	193	35	17	264	301
Roots													
Initial	486	27	31	318	80	21	477	2	57	40	21	120	357
Control	690	27	24	339	44	17	451	1	62	35	14	112	339
$NO_3$20	729	25	25	308	41	13	422	1	60	38	11	110	312
$NO_3$60	773	26	23	294	43	16	402	3	69	31	14	117	285
$NO_3$120	781	31	19	281	43	15	389	3	68	30	11	112	277
$NH_4$20	675	25	21	327	46	17	436	1	72	37	9	119	317
$NH_4$60	710	39	16	341	45	12	453	2	93	34	11	138	315
$NH_4$120	818	32	13	358	49	9	461	3	105	35	6	149	312
$NH_4NO_3$20	724	29	29	268	36	11	373	1	66	38	10	115	258
$NH_4NO_3$60	799	28	17	317	45	14	421	3	78	33	13	127	294
$NH_4NO_3$120	841	28	14	275	41	10	368	4	71	39	9	123	245

In the roots the concentrations of both cations and anions changed little except for SO_4^{2-} and Ca^{2+}. The Ca^{2+} concentrations in the roots were somewhat lower with nitrate treatments than with ammonium treatment, which resulted in a lower total cation concentration. The sulphate concentration was higher with ammonium treatment and the same was true for the total anion concentration. There existed differences in distribution between shoot and roots differences in distribution between shoot and roots for some nutrients. Generally, the nutrient concentrations in the shoots were higher than in the roots, especially for K^+, the concentrations of which in the shoot were usually more than 10 times higher than those in the roots. However, the concentrations of Ca^{2+} in the roots were much higher than those in the shoots.

Table 3. Total inorganic cation (C) and anion (A) contents (mmol $plant^{-1}$), total organic nitrogen content (mmol $plant^{-1}$) and $\Delta(C\Delta\text{-}A)/\Delta N_{org}$ with respect to the nutrient contents at the beginning of the experiment.

	ΣC	ΣA	C-A	N_{org}	$\triangle(C\text{-}A)/\triangle N_{org}$
Initial	7.26	2.16	5.10	9.14	
Control	15.64	5.30	10.34	20.93	0.44
NO_3 20	18.85	6.10	12.48	27.16	0.45
NO_3 60	21.33	6.01	15.32	38.67	0.41
NO_3 120	16.96	4.46	12.50	29.42	0.43
$NH_4$20	14.85	6.20	8.65	18.49	0.32
$NH_4$60	12.29	5.26	7.03	17.91	0.19
$NH_4$120	11.47	5.52	5.95	18.76	0.02
$NH_4NO_3$20	16.52	6.33	10.19	21.58	0.35
$NH_4NO_3$60	18.05	6.62	11.43	30.92	0.33
$NH_4NO_3$120	15.43	6.73	8.70	28.75	0.26

Carboxylate production

The total inorganic cation and anion contents, total organic nitrogen content and $\Delta(C\text{-}A)/\Delta N_{org}$ with respect to the nutrient contents at the start of the experiment are given in Table 3.

The total cation contents of the whole plants fertilized with nitrate were higher than those of the plants receiving ammonium, while the total anion contents of whole plants receiving nitrate were slightly lower or higher than those given ammonium. This resulted in a higher carboxylate production in the plants fertilized with nitrate. The ratio between the production of carboxylate and production of organic nitrogen $\Delta(C\text{-}A)/\Delta N_{org}$ was constant in the plants receiving nitrate.

$\Delta(C\text{-}A)/\Delta N_{org}$ obviously declined with increasing ammonium supply for the plants fertilized with ammonium, nearly reaching a value of zero at the 120 mg kg^{-1} NH_4-N level, which means there was no net production of carboxylate at this level. As for the mixed nitrogen source, $\Delta(C\text{-}A)/\Delta N_{org}$ values were intermediate between those of the nitrate and the ammonium-fed plants.

Conclusion

The growth of the plants fertilized with ammonium was not as good as the control treatment. The growth of the plants fertilized with ammonium nitrate did not differ significantly from that in the control or nitrate treatment, but was usually much better than that in the ammonium treatment. An increase in N supply raised the N concentrations in the plant regardless of the sources. Free nitrate concentrations in the plant were low except that at the highest level of nitrate and ammonium nitrate. Free ammonium concentrations all exceeded very low levels for all forms and levels of nitrogen. Total cations concentrations in the shoot varied little with N level in the ammonium and ammonium nitrate treatments, while those in the shoot increased with N level in the nitrate treatment. The treatments had little effect on the anion concentrations in the shoot except in the case of sulphate. In the roots the concentrations of both cations and anions changed little except for SO_4^{2-} and Ca^{2+}. There existed differences in distribution between shoot and roots for some nutrients. The ratio between the production of carboxylate and the production of organic nitrogen $\Delta(C\text{-}A)/\Delta N_{org}$ was constant in the plants receiving nitrate. $\Delta(C\text{-}A)/\Delta N_{org}$ obviously declined with increasing ammonium supply for the plants fertilized with ammonium. As for the mixed nitrogen source $\Delta(C\text{-}A)/\Delta N_{org}$ values were intermediate between those of the nitrate and the ammonium-fed plants.

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